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X-Ray Observations of Supernova Remnants
-Birth of Neutron Stars and Their Evolution-

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ABSTRACT

We presented some topics with the Ginga satellite related to neutron stars. We found that most of the Crab-like SNRs so far observed have power -law spectra with photon index of about 2. Observations of newly discovered X-ray pulsars in the Scutum region suggest that they have a smaller magnetic field than that of usual X-ray pulsars. A peculiar pulsar in the SNR G109-1.0 was found to have relatively small magnetic field in spite of its young age. A search for low mass X-ray binaries (LMXBs) near the Galactic center revealed that the total number of LMXBs does not increase drastically.
Keywords: Neutron star, Supernova remnant, X-ray binary

1. Introduction

The X-ray emission from supernova remnants (SNRs) has two origins: one is thermal emission from a thin hot plasma which is heated by a shock wave,and the other is non-thermal synchrotron emission powered by the rotational energy of a central neutron star. In general, the former emission shows shell structure, while the latter shows filled center structure. From these morphologies, SNRs are often classified into shell-like and Crab-like SNRs.

Since a neutron star is born with a supernova explosion, the study of SNRs which include a neutron star is of particular interest for the birth and evolution of a neutron star.

Comprehensive work on X-ray emitting SNRs has been carried out with the Einstein observatory by Seward (1990) and others. They observed about 80 Galactic supernova remnants, and 47 SNRs were found to be X-ray emitters. In the X-ray catalogue of SNRs (Seward 1990), about 20 SNRs belong to the Crab-like class which may include a neutron star. Among them only 7 have been found to exhibit pulsations either in X-ray or radio bands. Therefore we need more study for a pulsation search from other Crab-like SNRs. In section 2, we report X-ray observations of Crab-like SNRs.

The detection of cyclotron absorption features established the picture that the massive X-ray binary sources (X-ray pulsars) have a large magnetic field of more than 10^{12} Gauss. In sections 3 and 4, we will discuss another class of X-ray sources with a smaller magnetic field than the usual X-ray pulsars.

The current model that low mass X-ray binaries (LMXBs) will evolve to milli-sec pulsars after exhausting their accreting gas from the companion stars has, however, the serious problem that the birth rate of milli-sec pulsars is one or two orders of magnitude larger than that of the progenitor LMXBs. In section 5, we will report the results of the search for low luminosity LMXBs near the Galactic center.

2. Ginga Observations of Crab-like SNRs

2-1 pulsar search from Crab-like SNRs.

Using the Ginga satellite, Aoki (private communication, 1990) has carried out Fourier analysis of four Crab-like SNRs and set an upper-limit for the pulse amplitude. These values are listed in Table 1. The flux ratio of pulse amplitude to the total synchrotron nebula are all less than a few percent. We note that the ratio of Crab nebula, MSH15-52 and 0540 are about 10, 10 and 40 percent, respectively. Therefore these upper-limits are significantly smaller than those of known pulsars.

2-2 X-ray spectrum

The X-ray spectrum from the Crab nebula shows a non-thermal power-law spectrum with a photon index of about 2.0. Another Crab-like SNR Vela -X shows central X-ray emission which is from a synchrotron nebula. The X-ray spectrum of this synchrotron nebula has been reported as a power-law shape of a photon index of about 2. For MSH 15-52, Kawai et al (private communication, 1990) observed the X-ray spectrum of the pulsed component and non-pulsed component separately. The photon index of the pulsed component is smaller than 2.0, while that of the non-pulsed component is about 2.0. Asaoka and Koyama (1990) have observed other Crab-like SNRs; 3C58, G21.5-0.9 and CTB87, and found that they all have a power-law spectrum of photon index of about 2 (see Table 2). A question is why all or most of the Crab-like SNRs have nearly the same photon index although the age and luminosity are different from each other. Apart from this question, our results may provide an empirical tool to search for the Crab-like SNRs using the X-ray spectrum.

With this method, we can identify the synchrotron nebula even if its central pulsar beam is out of the line of sight, because the X-ray flux from the synchrotron nebula would be independent of the beaming angle of the central pulsar.

Table1 Upper limit of X-ray pulsation

Name	Pulse amplitude (count/s)	amp/total (%)
Kes 73	0.33	1.0
CTB87	0.21	4.0
Vela X	0.12	0.2
W28	0.12	0.5

Table 2 Photon index of Crab-like SNRs

Name	Photon index	log N_H
G21.5-0.9	1.88 $\pm$ 0.05	22.1$\pm$ 0.1
CTB87	2.5±0.6	22.1± 0.6
MSH15-52	2.04±0.11	21.8±0.2
3C58	2.2± 0.1	<21.5

3. A colony of X-ray Pulsar and SNRs

The Tenma and Ginga satellites have discovered the 6.7kev emission line along the inner Galactic plane (Koyama et al. 1986, Koyama et al. 1989). Since the 6.7keV line is likely due to highly ionized iron atoms, the origin is optically thin hot plasma. The temperature of the plasma was determined to be about 5-10keV. The origin of this hot plasma is shock heated gas such as from a supernova explosion. Figure 1 shows the hot gas distribution using the probe of the 6.7keV iron line flux. We find a shoulder at about 30 deg. The position near 30 deg corresponds to a place of strong enhancement from a molecular cloud and is refered as the 5-kpc Arm. The shoulder structure of 6.7kev intensity may suggest that the 5-kpc Arm is a site of many supernova explosions. Supernova explosions would make many neutron stars, some of which would be binary X-ray pulsars. We have extensively searched for binary pulsars along the Galactic plane and have found many new pulsars near the position of l=30 deg. Since the hydrogen column density of these new X-ray sources is very large, we suggest that these sources are lying at a large distance of about 10 kpc. This suggests that the new X-ray pulsars are really embedded in the 5-kpc arm. (Koyama et al. 1990).

The X-ray spectra of these new sources are shown in figure 2, exhibiting steep falls near about 10kev, which is much lower than the usual X-ray binary pulsars. From the cut-off energies in the spectra of binary X-ray pulsars, Makishima (this volume) pointed out that the cut-off structure is due to a cyclotron absorption. If we apply this idea to the new X-ray pulsars, the magnetic field is estimated to be around 10^{11}-10^{12} Gauss, which is significantly smaller than that of the usual X-ray pulsar. Since these new pulsars are transient, they are likely to be Be star binaries. The typical age of Be star is about 10^7 years which is one order of magnitude smaller than that of the usual massive binary pulsars.

4. A binary X-ray pulsar in a SNR

The X-ray pulsar 1E2259+586 is a unique binary X-ray pulsar embedded in a young SNR G109-1.0. Since the pulse period change is too small to power the X-ray flux, 1E2259+586 could not be an isolated neutron star but would be a binary X-ray pulsar. Still the very slow spin-down trend is unusual among typical binary X-ray pulsars. The spin period history shows a long term spin-down trend with a small rate of $\dot{P}/P = -10^{-13}$ yy^{-1} (Iwazawa et al. 1990, private communication). The slow increase of the pulse period indicates that the accretion torque is small although the X-ray luminosity is moderately large (10^{36} erg/sec). This may be the case that the Alfven radius is nearly equal to the co-rotation radius. Using this relation, Koyama et al. (1986) found that the magnetic field is about 5×10^{11} Gauss. The X-ray spectrum is also unusually soft. From the X-ray spectrum observed in 1989 and 1990, we found a hint of cyclotron line feature near 7kev and near 14kev as a second harmonic. This also supports the idea that the magnetic field is smaller than the typical binary pulsar.

The age of the SNR G109-1.0 can be estimated from the temperature, diameter and X-ray luminosity and is of the order of 10^4 years. Thus we have found an example of a young neutron star having relatively a weak magnetic field.

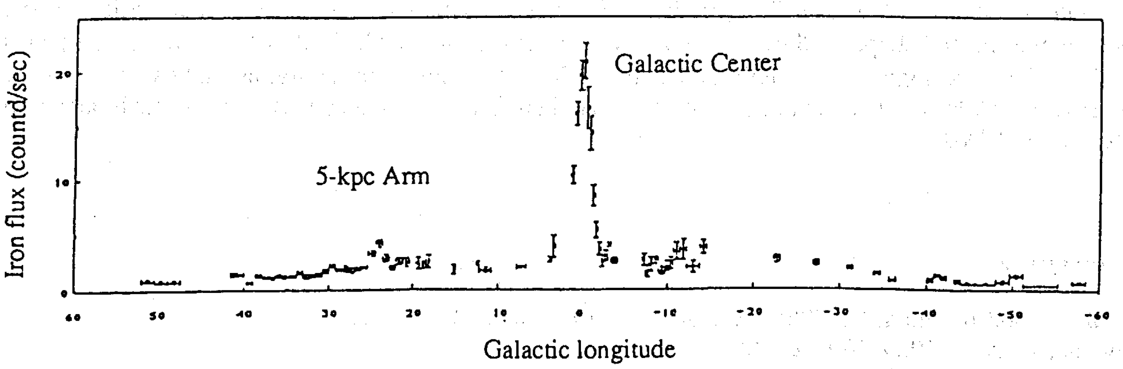

Fig.1 The scan profile of the 6.7kev line flux and 2-10kev band flux along the galactic plane.

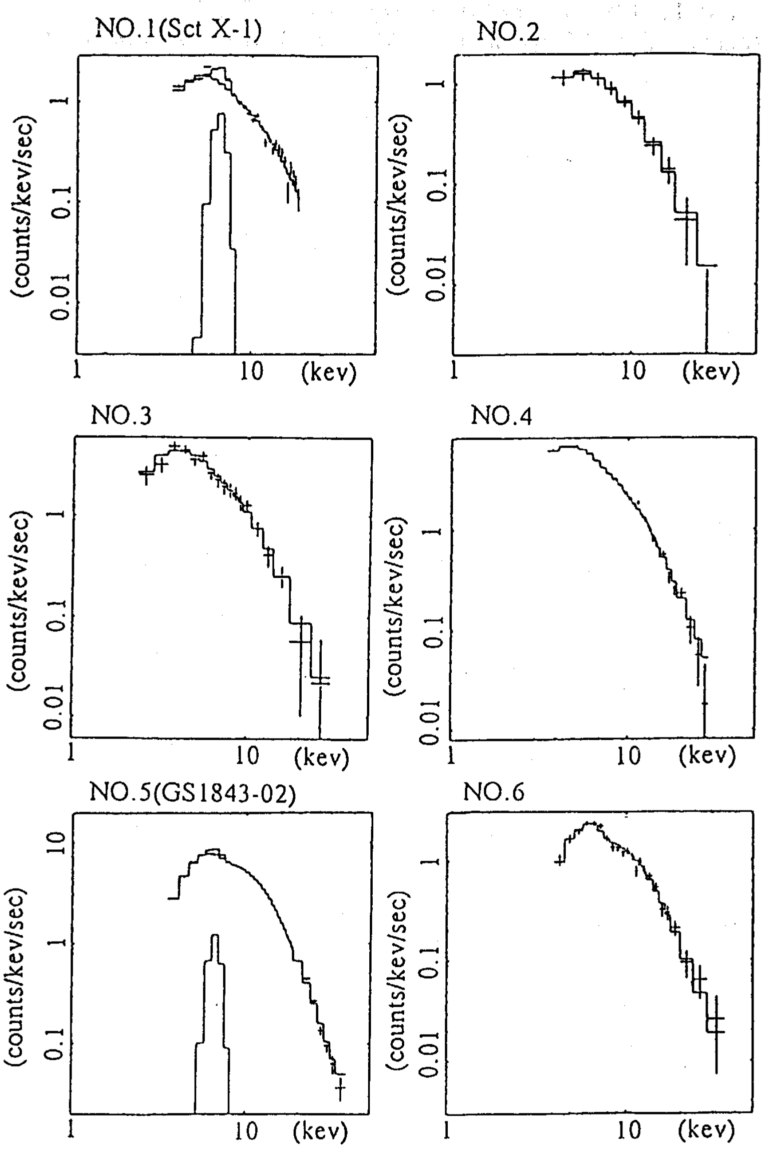

Fig.2

The X-ray spectrum of New X-ray pulsars near the 5-kpc arm.

5. Low mass Binary X-ray sources and milli-sec pulsars.

The progenitor of milli-sec pulsars has been suggested to be low mass X-ray binaries (LMXBs). However several authors pointed out that the birth rate of milli-sec pulsars could be one or two orders of magnitude larger than that the progenitor LMXBs. In order to estimate the total number of LMXBs, Yamauchi and Koyama (1990) have carried out survey observations near the Galactic bulge region and have found nine new X-ray sources above the detection limit of about 10^{35} erg s^{-1}. Among them, seven are classified to be LMXBs based on the spectral shape. In the same region we detected catalogued LMXBs which are brighter than 10^{36} erg s^{-1}. Therefore, we suggest that total number of LMXBs does not increase dramatically with a more sensitive survey of the Galaxy. This remains a problem, that there is a discrepancy between the birth rates of milli-sec pulsars and LMXBs.

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